CORAL REEF MAPPING IMPLEMENTATION PLAN

MAPPING AND INFORMATION SYNTHESIS WORKING GROUP of the U.S. CORAL REEF TASK FORCE

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I. ABOUT THIS DOCUMENT

This document was produced to support the U.S. Coral Reef Task Force (CRTF), created by Executive Order P.L. 13089, which calls for the conservation and protection of the nation's coral reefs. The Mapping Implementation Plan (MIP) complements the CRTF's Mapping and Information Synthesis Working Group's (MISWG) mapping strategy document, which was presented and endorsed by the CRTF at its March 1999 meeting in Maui, Hawaii (MISWG 1999a). The Task Force requested that the Mapping Implementation Plan be completed by November 1999 to enable mapping efforts to move forward in 2000. The MIP provides the first comprehensive framework to map all U.S. coral reef habitats by 2007 using a suite of satellite, aircraft, and underwater data-collection platforms. The MIP is an evolving document that will be routinely revised and updated based on Working Group and user comments, funding constraints, and changes in technology. **This document will be used as source material for the coral reef mapping section of the U.S. CRTF Action Plan.**

II. BACKGROUND

U.S. Coral Reef Task Force and the Mapping and Information Synthesis Work Group

On June 11, 1998, President William Jefferson Clinton announced Executive Order 13089, "Coral Reef Protection," to conserve and protect U.S. coral reef ecosystems and those species, habitats and other natural resources associated with coral reefs in all maritime areas and zones subject to U.S. jurisdiction (i.e., federal, state, territorial and commonwealth waters). The Task Force's duties are organized around four thematic areas: (1) coral reef mapping and monitoring, (2) research, (3) conservation, mitigation, and restoration, and (4) international cooperation. To implement Executive Order 13089, several working groups were formed to address and develop action plans for each thematic area.

With respect to coral reef mapping, Executive Order 13089 directs the Task Force, in cooperation with state, territory, commonwealth, and local government partners, to coordinate a comprehensive program to map and monitor U.S. coral reefs. The National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and National Aeronautics and Space Administration (NASA) were designated as the federal co-chairs of the Mapping and Information Synthesis Working Group to lead the development of a comprehensive coral reef mapping plan. The Working Group's overall goal is to develop a strategy for creating a set of comprehensive, consistent U.S. and territory coral reef ecosystem maps and a map information synthesis capability. The Executive Order states that to the extent feasible, remote-sensing capabilities should be developed and applied to this effort, and that local communities should be encouraged to participate. In response to these guidelines, the Working Group has developed three primary documents to implement the coral reef mapping component of the Executive Order.

The first two documents, (1) *A Strategy to Map State, Commonwealth, Territory, and Freely Associated State Coral Reef Ecosystems in the U.S.* (MISWG 1999a), and (2) *Summary of Issues and Proposed Actions. Report of the Mapping and Information Synthesis Working Group to the Coral Reef Task Force* (MISWG 1999b), were presented at the second U.S. CRTF meeting in March 1999. The Task Force recommended that the Working Group's proposed strategy be adopted, and directed the Working Group to develop a companion document to implement comprehensive mapping of U.S. coral reef ecosystems. ***Depending on resource availability and mapping techniques selected, several additional documents will be required to outline specific protocols and procedures for data collection, data processing, digital map development, and institutional partnerships to conduct the work. Based on priorities presented in the MIP, these documents will be developed as mapping activities proceed forward.***

This Mapping Implementation Plan reflects the feedback to the Strategy document, the summary report, and numerous Working Group meetings. A brief summary of these documents and meetings is provided below as background information fundamental to developing the plan. These documents and other background materials, as well as results from the first and second meetings of the Task Force, can be viewed on the Web at <http://coralreef.gov/>. In the working group's documents, we define mapping as determining the location and extent of benthic habitats, assessment as characterizing the health of benthic (e.g., coral) communities, and monitoring as the ability to detect and measure changes over time in benthic habitat communities. It is important to recognize that "mapping" has many components including development of digital shorelines, high resolution bathymetry, habitat classification systems, and digital habitat maps.

While our primary goal is to produce coral reef ecosystem maps, the working group fully recognizes the importance of merging these map products with other information. Information acquired through coral reef monitoring activities, some of which have been going on many years, needs to be incorporated. Because the coral reef maps will be developed and distributed in geographic information systems (GIS), incorporating these other types of information will create a "tool" that can be used by researchers and managers to study and evaluate the condition of the ecosystem. Data collected in the past can be compared to current conditions to measure change. Data from other sources, such as industrial discharge permits, land-based water quality monitoring activities, public health-related monitoring activities and others, can be integrated and looked at simultaneously. In addition, other thematic map layers, such as the land use activities, locations of industrial discharge pipes, water quality monitoring stations, river inputs of fresh water, navigation routes, and commercial and non-commercial marine species spatial distributions can be incorporated into the GIS. The result is a powerful, flexible decision support tool for coral reef ecosystem research, conservation, and management. For example, such a tool can be used to: develop better marine environmental education programs that stress the importance of coral reef ecosystems and their conservation; identify and evaluate areas where coral reef management efforts are needed immediately; characterize and evaluate the status of the essential habitat of commercial and non-commercial marine species; develop management strategies for marine protected areas; predict and model the potential damage to populated areas caused by severe weather; and support activities that evaluate and develop capabilities to conduct long-term monitoring and change analyses.

Summary of Working Group Issues and Actions

The initial Working Group meetings resulted in several key actions and identified important issues concerning coral reef mapping throughout the U.S., and it's territories, commonwealths, and freely associated states. The Working Group agreed to identify technologies that should be used to collect data and to recommend what type of digital coral reef maps (e.g., spatial resolution) should be developed based on input from scientists and local and regional coastal managers. This resulted in a multidisciplinary Working Group that included members from federal, state and local governments, academia, the private sector and private citizens (Appendix 1). A complete list of partner institutions can be found in MISWG (1999a).

The Working Group agreed that both short-term (1-5 years) and long-term (>5 years) coral reef mapping goals should be identified. The Working Group narrowed the definition of map information to that which can be incorporated into a geographic information system (GIS). Thus, maps should be digital, and information layers should be tied to a geographic base map. Although the mapping effort will focus on coral reefs, the Working Group recommends that associated shallow benthic (bottom) habitats, such as seagrass, sand, mangroves, and hard substrate, should also be mapped.

The first activity of the Working Group was to inventory existing hard-copy and digital coral reef map products for U.S. coral reef ecosystems. This activity is described in the section of the plan entitled "Mapping and Information Synthesis - Existing Data and Products," and in Appendix 2. A wide variety of data sources of varying content and quality were identified and compiled. These will be used to aid in the development and validation of upcoming digital coral reef map products. This will lead to discussions regarding the distribution of digital data.

The Working Group identified two high-priority issues: (1) the lack of digital maps of coral reefs, and (2) an inability to detect changes in coral reef distribution, health and ecology over time.

(1) Digital Maps

Baseline digital maps do not exist for all coral reef ecosystems within the United States and its territories. The lack of map information is particularly evident in the Pacific.

To address the need for a comprehensive set of baseline maps, the Working Group proposed in its mapping strategy the short-term goal of:

Producing comprehensive digital coral-reef ecosystem maps for all U.S. State and Territories within five – seven years, beginning in the Pacific where critical gaps presently exist.

The feature resolution of comprehensive digital coral reef maps will range from 1 sq. km (satellite technology) to 1 - 5 sq. m (aircraft; e.g., air photos) depending on available resources, local mapping requirements and available technology. The Working Group and the user community defined high-resolution maps as those that depict features less than or equal to 5 meters in size (features typically visible in aerial photography of 1:12,000 to 1:48,000 scale). This resolution is required for high-priority areas as defined by island and state partners. In addition, the Task Force recommended that the *Benthic Habitats of the Florida Keys* CD-ROM serve as a prototype for the type of research and management capability desired for other coral reef ecosystems (NOAA/FMRI 1998). While it may not be feasible to map all U.S. coral reefs (estimated to be 17,000 sq km) to this level of detail, the *Benthic Habitats of the Florida Keys* product was identified as a model for areas that require high-resolution maps. Where possible, very fine resolution data (e.g., <1 m), such as maps derived from scuba observations, should be integrated into the digital mapping framework. It is important to note that these digital maps will be developed using commercially-available software that simplifies the translation of data into numerous formats. In addition, the digital data will be made available as soon as possible via the Internet. Lastly, the data will be standardized to current horizontal and vertical datums.

(2) Detecting Change

The technology does not presently exist to routinely monitor change in coral reef ecosystems over time in an operational, cost-effective procedure. A distinction must be made between the role of remote sensing in producing a single, comprehensive map (baseline) of a coral reef at a given point in time, versus the role of remote sensing in long-term monitoring. The Working Group recommends routine updates to the Nation's benthic habitat maps across regional and local spatial scales. Thus, a second issue identified by the Working Group concerns the need to develop cost-effective methods of mapping reefs and of conducting long-term change analyses. Remote sensing technologies are rapidly advancing from the research and development mode to more applied coral reef mapping efforts. **However, *no region-wide* (e.g., the Caribbean), *high-resolution* coral reef maps have been produced using remote sensing technology (e.g., hyperspectral imaging), nor have long-term change analyses been conducted.**

To develop the technology to detect change, the long-term goal is to: *Develop, within 10 years, remote sensing technologies for routine, operational monitoring of coral reef ecosystems.*

In the near-term, remote sensing research and associated experiments to map coral reefs and other benthic habitats should lead to improved methods of acquiring and updating digital baseline maps. However, long-term monitoring requires the maintenance of stable, well-calibrated instruments, and analytical methods capable of distinguishing the variability of the reefs from variability in the water quality conditions present in the overlying water column. Therefore, based on the two concerns discussed above, applied and experimental remote sensing technologies should be used and advanced to meet the challenge of developing consistent and comprehensive digital coral reef ecosystem maps for the nation, as directed by the Task Force.

III. WHY REMOTE SENSING?

Remote sensing (e.g., aerial photography, satellite/airborne spectral imaging) of benthic habitats is the only option to obtain synoptic data for large coastal and island areas. This provides a view that is not possible from *in situ* field surveys, which are more expensive and time consuming to perform. Remote sensing, however, cannot be considered a replacement for field surveys, both of which should be viewed as complementary efforts. Field surveys are required to interpret remotely sensed images and to evaluate the accuracy of such interpretation. Factors affecting the availability of remotely sensed data include cloud cover, sea state and water clarity. To date, most remote sensing efforts utilizing spectral imaging (e.g. hyperspectral data) have been directed toward research of potential applications, with little attention paid to operational realities (e.g. cost of existing capabilities to discriminate and map coral environments). Regardless of these constraints, remote sensing remains the only viable means of producing consistent and comprehensive coral reef ecosystem maps over the next 5 to 7 years.

Executive Order 13089 encourages the use of existing remote sensing technologies to map U.S. coral reef ecosystems, and supports continued research to refine its capabilities as an applied ecosystem management tool for coastal managers. The Working Group recommends a hierarchical approach to mapping these coral reef habitats, using a suite of remote sensing platforms ranging from satellites, to aircraft, to *in situ* field surveys.

Remote sensing technology can generally be grouped by the resolution (pixel size) of the resulting data. This resolution is affected by both the altitude of the platform from which data are collected and the design of the instrument or camera. First, *low-resolution satellite platforms,* such as NASA's SeaWiFS (Sea-Viewing Wide Field-of-View Sensor) and NOAA's AVHRR (Advanced Very High Resolution Radiometer) acquire synoptic data that range in pixel size from 1 to 10 km^2. *Moderate-resolution satellite platforms* such as LandSat, SPOT, and human-occupied spacecraft (Space Shuttle, International Space Station) produce data with pixels ranging from 10 - 30 m^2, depending on the specifics of the acquisition. Instruments mounted on *fixed-wing aircraft and helicopter platforms* range in resolution, depending on the altitude and specific technology used, from sub-meter to 5 m features. A final category of *classified remote sensing images* from the National Technical Means (NTM) Program would also have high resolution. NOAA has requested access to selected NTM data to produce benthic habitat maps and to augment civilian data acquisition of benthic habitat data.

Aircraft Platforms

Historically, high-resolution benthic habitat maps of large coastal areas have been produced from color aerial photography (NOAA/FMRI 1998). An important advantage to using aerial photographs is their widespread availability and ease of analysis. Color aerial photographs at scales of 1:12,000 to 1:24,000 have a resolving power of 0.5 to 1 m. However, conventional photo-interpretation techniques define polygons at 10 to 20 m in size due to prohibitive time constraints and the practical difficulty of mapping smaller features. Even with such "scaling up," standard photo-interpretation is very time consuming. Experts must manually classify habitats based on textures and colors in the image and their own knowledge of the distribution of benthic habitats. An alternative to this approach is to digitally scan the photo at a resolution consistent with its scale and then classify the resultant digital image using image-analysis software. While this approach is much faster than the conventional method, a disadvantage is that the digital image has poor spectral resolution (caused by overlapping, broad color bands, i.e., red, green, and blue), which limits the analyst's ability to discriminate between certain types of benthic habitats.

In an effort to expedite the analysis of aerial photographs, experiments are underway that combine the advantages of the above techniques. In this technique, aerial photographs are digitally scanned and a portion of the classification effort is computer automated as a "preclassification" step to standard photointerpretation. This technique shows promise for increasing the efficiency of deriving benthic habitat maps from photographs.

Multi- and hyperspectral remote sensing systems offer the tremendous advantage of increased spectral resolution. Multispectral systems have been successfully used to map coral reef ecosystems and to identify other benthic habitats, such as sand, algae and seagrass (Mumby et al. 1997). Recently, hyperspectral sensors have been used in relatively small geographic areas to map benthic habitats, including coral reef features (Mumby et al. 1998). Hyperspectral data contain far more information (i.e., characteristic spectral signatures) per image than a single conventional red-green-blue (RGB) color image (photograph), and significantly more information than multispectral data (Holasek et al. 1997). These studies show great promise for digital mapping of coral reef habitats. However, hyperspectral mapping generates large data sets and, to date, no regional benthic habitat maps have been generated from this technology. NOAA is currently conducting experiments in the U.S. Virgin Islands and Puerto Rico to explore the feasibility of synoptic habitat mapping using hyperspectral images.

Satellite Platforms

Satellite imagery has been used to map general benthic habitat types (e.g., sand, seagrass, coral, hard substrate) in coral reef environments. While lacking the spatial or spectral resolution of aircraft obtained data that enables detailed mapping, satellite imagery offers the advantages of increased frequency of coverage, extensive coverage at low cost, archival data and fast results. Satellite imagery also assures continuity across areas not covered by aircraft. At present, satellites can provide resolutions (pixel size) ranging from 1 km^2 to less than 10 m^2.

Moderate Resolution: Landsat Thematic Mapper (TM). This sensor has been used to map several types of bottom cover in coral reef environments (Mumby et al. 1997; Luczkovich et al., 1993). The TM can provide adequate resolution for planning aircraft missions, and also permits rapid response to reported bleaching events (e.g., at least several images per year in the Pacific, and biweekly coverage in the Caribbean). A TM sensor has been flying for 17 years. While data collection over coral reef regions has been rare, some key regions in the Pacific, such as Hawaii and Guam, have been covered at least once during this time, permitting some change analysis to be conducted. The launch of the Landsat 7 satellite potentially offers systematic, multispectral coverage of coral reefs at 30 m resolution, and panchromatic coverage at 15 m resolution. Unlike the earlier sensors, the TM on Landsat 7 is fully calibrated, allowing comparable processing for TM, aircraft and ocean-color sensors.

Moderate Resolution: Space Shuttle and International Space Station. Medium-format cameras have been used to photograph Earth from low orbits (median 176 nautical miles, 326 km) since the early 1970s. As with color aerial photography, color orbital photography can be interpreted from prints, or digitized in three bands (red, green, blue) and classified (Webb et al. 1999; Robinson et al. 1999). A nadir-looking photograph will have resolution ranging from 10 to 50 m^2, depending on the specifics of the mission and camera. Although the photographs are more variable in look angle than other remote sensing platforms, most slightly oblique photographs are also suitable for use as remote sensing data (Robinson 1999). The digital images can be referenced to a map so that they can be combined with other mapping data. Because data is collected by human observers, it has been pre-screened for heavy cloud cover. Reef areas, especially in the Pacific, have been routinely photographed for the last 20 years. Continuous observations from the International Space Station (ISS, to be occupied beginning in the year 2000) will provide opportunities to collect imagery for those areas that have not yet been photographed under low-cloud conditions. ISS photographic capabilities include medium-format cameras, electronic still cameras, and high-definition television. ISS will also be equipped for mounting other instruments, including hyperspectral sensors, that may be useful for reef mapping at moderate resolutions.

Table 1. Existing databases and products

	Digital Coral Reef Maps	Satellite Imagery	Recent Aerial Photography (<10 yrs.)	Aerial Hyperspectral Data	Digital High Resolution Shoreline	Digital Shallow Water Bathymetry
American Samoa	Unavailable/Unknown	Available	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
CNMI	Incomplete	Available	Incomplete	Unavailable/Unknown	Incomplete	Unavailable/Unknown
Florida Keys	Incomplete	Available	Available	Incomplete	Available	Available
Fed. Sts. Micronesia	Unavailable/Unknown	Available	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Guam	Incomplete	Available	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Main 8 Hawaiian Is.	Incomplete	Available	Available	Incomplete	Incomplete	Incomplete
NW Hawaiian Is.	Unavailable/Unknown	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Marshall Islands	Unavailable/Unknown	Incomplete	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Palau	Unavailable/Unknown	Incomplete	Incomplete	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown
Puerto Rico	Incomplete	Available	Incomplete	Incomplete	Available	Available
U.S.Virgin Islands	Incomplete	Available	Available	Incomplete	Available	Available
other†	Unavailable/Unknown	Incomplete	Available	Unavailable/Unknown	Unavailable/Unknown	Unavailable/Unknown

Available

Incomplete

Unavailable/Unknown

†Johnston, Palmyra, and Wake Atolls, Baker, Jarvis, and Howland Islands, and Kingman Reef.

Low-resolution: SeaWiFS and AVHRR. The ocean color sensors in SeaWiFS have the potential to provide a standard global coverage of reef areas at 1 km resolution. These sensors can identify shallow water areas, potentially distinguish live bottom from dead bottom, and provide consistent positional accuracy. These functional capabilities at this resolution have been demonstrated with 1-km data from the NOAA's AVHRR satellite, which has been used to produce the first accurate estimates of seagrass loss in Florida Bay and the Florida Keys during the past 10-years (Stumpf et al. 1999). One advantage to use of SeaWiFS is the ability to rapidly produce global color-based maps that can serve as a reference with which to plan the acquisition of higher resolution data, and to organize higher resolution data as it is acquired and processed.

Other Sensors: MOS (500 m) and SPOT (10-20 m) data can be incorporated as appropriate.

Hierarchical Mapping Strategy

Based on the requirements and needs identified by the Working Group, and the Task Force objective to comprehensively and consistently map U.S. coral habitats, a phased-in, multiplatform approach is recommended. All U.S. coral reefs should be mapped with low- resolution platforms (e.g., satellites). The Working Group recommends that the Long-Term Acquisition Plan of the Landsat 7 mission continue to obtain imagery over the world's coral reefs and make these data easily available for many users. Local, high-priority areas will require relatively high-resolution maps derived from sensors mounted on aerial platforms, including multi- and/or hyperspectral instruments and color photographs.

As stated in Section I, this document is an evolving one because its recommendations are likely to change based on changes in funding levels, program priorities and technology. Commercial firms are now taking many of the existing remote-sensing mapping tools out of the research and development mode and into the realm of applied habitat mapping. Several commercial and Department of Defense satellites proposed for 2000 and beyond, for example, may provide better spatial resolution at lower costs. Thus, an area such as the Federated States of Micronesia, for which the Working Group currently recommends the use of Landsat 7 images, may ultimately be mapped via higher-resolution tools.

This plan does not contain detailed descriptions of the logistical requirements for the acquisition of digital data, post-processing of those data, validation of draft maps, and development of final digital coral reef ecosystem maps, bathymetry maps or shoreline maps. The Mapping and Information Synthesis working group will continue to work closely with our federal, state and local partners to ensure coordination among these agencies in completing these mapping activities. Also, as interim products, such as aerial photography, bathymetry, or high resolution shoreline are completed, these will be made available to our working group partners.

IV. MAP INFORMATION SYNTHESIS: EXISTING DATABASES AND PRODUCTS

ReefBase. Currently, the only uniform reef maps available for all the U.S. reefs are part of the larger set of maps compiled by the World Conservation Monitoring Center and distributed as part of ReefBase (ReefBase 1998, produced by the International Center for Living Aquatic Resources Management).

These maps were compiled from existing charts and information at a uniform 1 km pixel size. Although the maps are uniform in scale, they are presently constrained by data source limitations and data interpretation. ReefBase also accumulates ground-based data on aquatic resources that are integrated with the maps. Successful pilot projects have been completed for integration of NASA data with WCMC/ ICLARM projects. SeaWiFS data can be used to improve the accuracy of the ReefBase maps. Georeferenced Space Shuttle photographs have been used as base maps for display of ReefBase attributes in a prototype GIS.

An initial step in developing this plan was to obtain information for all U.S. islands on the availability of digital benthic habitat data and associated baseline information, such as digital shorelines and bathymetry. The Working Group conducted two data inventories: (1) a mail questionnaire, and (2) a series of site visits to Florida, the U.S. Virgin Islands, Puerto Rico, Hawaii, Guam, Saipan and American Samoa. Table 1 provides an overview of the inventory results. See Appendix 2 for a summary of data and information availability for each island, state and territory. In addition to the information compiled on the availability of digital habitat data, many Island hardcopy and technical reports exist that will aid in interpreting new acquired habitat data and provided a historical perspective.

V. MAPPING IMPLEMENATION

Baseline Mapping Requirements

(1) Shallow Water Bathymetry

Bathymetry is a critical thematic data layer for many mapping activities. Bathymetry depicting water depths of less than 100 m is needed to identify and locate navigation hazards and shipping channels, predict and manage the damage from floods and storms, identify and monitor critical fish habitat, and document the location and extent of shallow coral reef ecosystems. Bathymetry also is required to fully utilize remotely sensed data to correct for light attenuation. Light received by the sensor is affected by the distance that it must travel through the water column. Fortunately, most corals are found in shallow-water environments of less than 30 m. Bathymetry of the Pacific Islands has not been extensively acquired. Recent efforts to gather high-resolution shallow water bathymetry have focused on southern Molokai, Oahu, Kauai, and Maui. Elsewhere, low-resolution bathymetry from mapped sources, such as NOAA nautical charts, has been used. It has, however, been more than 50 years since some of this information was updated. As a result, efforts should continue to acquire high-resolution bathymetry for shallow waters. Deeper reef bathymetry is also not generally available for the Pacific, Florida or much of the U.S. Caribbean, and efforts need to focus on these updating and improving these data sets.

Several technologies to measure bathymetry exist. Bathymetry for certain applications and depths to 25 m can be derived from remote-sensing techniques, although optimal conditions of water clarity are required. Airborne LIDAR, which utilizes an active, laser-based technology, can produce very accurate (+/- 30 cm), detailed bathymetric charts to 25-50 m depth in clear waters. In partially turbid waters, the LIDAR system can provide bathymetry to depths approximately 2.5 times the depth at which aerial photography can depict the ocean bottom. Costs of LIDAR range from $900 to $1,800 per sq km depending upon the horizontal spatial resolution needed. These costs include both data collection and the production of digital bathymetry maps.

(2) Deep Water Bathymetry

Deep water (> 50 m) bathymetry also is crutial for many mapping activities, including coral reef ecosystem mapping. Ship-based acoustic surveys using multibeam depth sounders have successfully produced bathymetric maps with vertical accuracies of +/- 15 cm from depths 10 m to 500 m and greater. Bathymetric data collected with multibeam systems is georeferenced, thus providing valuable information for identifying specific features or for follow-up mapping to detect change. In addition to providing highly accurate bathymetric maps, the system provides backscatter, which can be used to map the roughness of the seafloor.

(3) Digital Shoreline Maps

Shoreline is a critical thematic layer because of its importance in linking land-based and water-based coastal zone management issues. An accurate, high-resolution shoreline is the base map upon which all other thematic data layers are superimposed. In addition, datum adjustments must be applied to the shoreline to properly place this key feature on the earth in a GIS. For the Caribbean islands, high-resolution (nominally, 1:20,000 scale) shoreline data are available. In the Pacific, accurate, high-resolution digital shoreline data are generally unavailable. NOAA nautical charts and USGS quadrangle maps are the most widely available sources of information. These maps have not been updated for many years, and generally are unavailable as digital data. Moreover, they are drawn in old datums and, in some cases, are known to depict islands as much as 1 to 2 nautical miles from their actual location on the Earth. Efforts must continue to develop accurate, high-resolution, datum-corrected digital land (shoreline) maps for the Pacific.

(4) Habitat Classification

A required step in developing digital map products is the formulation of a benthic habitat classification scheme. Work is under way in the Caribbean with Working Group members and other experts to develop a comprehensive classification system specific to that region. The approach involves developing a hierarchical biological and physical classification scheme based on the needs of the management community, the strengths and weaknesses of existing classification schemes for the area and, most importantly, the limitations of each technology (e.g., aerial photographs, hyperspectral). The digital data derived from each method can be used to generate maps depicting a certain level of classification. For example, aerial photographs can be used to produce maps that depict coral reef types, but are unsuitable for mapping individual species of coral. The more detailed the classification scheme, the more highly resolved the data must be to support the classification.

The development of a marine habitat classification scheme is under way in the Pacific as well. Holthus and Maragos (1995) have produced a detailed classification system that covers many island geomorphologies and substrate types that occur throughout the Pacific. More recently, the Pacific Marine Environmental GIS Work Group, a consortium of federal, state and academic partners, is leading the development of an updated classification system for the Pacific Islands. The applicability of these classification schemes to the features identifiable in the remotely-sensed imagery will need to be evaluated.

In summary, accurate, high-resolution bathymetry and shorelines are important data sets that aid in the development of coral reef ecosystem maps. In addition, a hierarchical classification system must be developed to map benthic habitats.

Overview of Island/State Mapping Requirements and Priorities

Representatives of the Working Group met with state and island partners in a series of meetings and site visits to determine mapping requirements in these areas. Based on the consensus of the territory and state Working Group partners, priorities were determined for geographic areas to be mapped, preferred map resolution, and proposed products. These priorities are summarized in Tables 2 and 3, and include information on where, when, and how to map coral and other benthic habitats. Most importantly, cost estimates are provided for various remote-sensing technologies. The cost estimates have been broken down by high- and low-resolution mapping platforms.

It is important to note that in developing the following information on coral mapping requirements and needs, the Working Group treated the Mapping Implementation Plan as a high priority for each island. When other activities are integrated into the U.S. CRTF Action Plan, however, the mapping of coral reefs may range from high to low priority relative to other important action items identified by island and state partners. The overall priority placed on mapping is presented in the **All U.S. Islands Plan.** ***This comprehensive coral reef management, research, monitoring and assessment document will strongly influence the U.S. CRTF Action Plan.***

The Islands agree that coral mapping is a high priority, however, it is felt that funding for this important task should be accomplished through internal reprioritization of Federal agencies existing budgets as directed in the Presidential Executive Order. However, reprioritization of funds will only enable digital high-resolution maps to be completed for a portion of U.S. coral reef ecosystems within five years. If new funds are provided by Congress, the priority for allocation remains with the Islands, as adopted as a resolution by the U.S. CRTF.

<u>Atlantic Ocean/Gulf of Mexico</u>

(1) Caribbean

In the U.S. Virgin Islands (USVI) and Puerto Rico, high-resolution benthic habitat maps are under development for the U.S. Virgin Islands and Puerto Rico. In 1999, NOAA's National Ocean Service (NOS) and National Marine Fisheries Service (NMFS) initiated a coral mapping study with a series of partners, including the USVI National Park Group (NPG) , the USVI Department of Planning and Natural Resources, and the Puerto Rico Department of Natural and Environmental Resources, and the USGS. The objective of the study is to consistently and comprehensively map the distribution of shallow-water coral reefs and other benthic habitats in and around these islands. Made possible through the strong commitment of many governmental, academic and private-sector partners, the study serves as a model for integrating a large number of partners to develop high-resolution digital maps of benthic habitats.

Data acquisition was completed in April 1999. NOAA aircraft were used to conduct color aerial photography and hyperspectral imaging. Color photographs were taken of all U.S. Virgin Island and the majority of Puerto Rico shorelines, and offshore to water depths of approximately 20 m. The aerial photography mission was flown primarily at an altitude of 24,000 feet (1:48,000 scale). An important complementary component of this investigation was a suite of airborne and waterborne hyperspectral experiments conducted at St. Croix and Buck Island, U.S. Virgin Islands, to determine the feasibility of mapping regional benthic habitats using hyperspectral remote sensing technologies. The pilot study is tentatively scheduled for completion by the end of 1999. Follow-up work includes: (1) completing the acquisition of aerial photography of Puerto Rico; (2) determining how best to process the aerial images; (3) developing a benthic habitat classification system that is appropriate for the area; (4) draft digital maps of benthic habitats; and (5) development and distribution of final products.

These maps will prove useful to a wide array of research and management activities. In both Puerto Rico and the USVI, coastal development and land use have been identified as primary stressors on coral reef ecosystems. Managers lack critical information that can help or assist them in regulating and evaluating status and trends of reef ecosystems and the effects of management decisions. Coral reef maps will serve as a basis to integrate monitoring, permit evaluation, land use activities and benthic habitat characterization. In addition to the need for coral reef maps, other thematic maps, such as bathymetry and land-use activity maps would greatly improve the ability of these islands to effectively manage and protect these resources.

As a result, the working group will work to identify and fill-in gaps that exist in the aerial photography and hyperspectral data. The working group will work to identify sources of land-use data and make these available too. The cooperative partnership that has been established with Puerto Rico and USVI has been instrumental in accomplishing the working group's goals. We will continue to work closely together, making interim products available as soon as possible and in developing technologies and training activities that can be used immediately to address coral reef management issues.

(2) Gulf of Mexico

In Florida, NOAA and the Florida Marine Research Institute used aerial photogrammetry techniques from visual overflight data to map approximately 60% of the benthic habitats of the Florida Keys coral reef ecosystem (NOAA/FMRI 1998). Digital benthic habitat maps were produced and published as a CD-ROM. That CD-ROM has been made widely available to the scientific and management communities. The identified benthic habitats were classified into 23 major "types" (e.g., sparse seagrass, patch reef, fringing reef). While this work could serve as a "model" for other Coral Reef Initiative efforts conducted in other regional ecosystems, it should be pointed out that the mapped areas would be subject to errors in classification and "non-identification." These problems stem from the methods of collecting and assimilating data from aerial photography, sub-optimal water transparency during overflights, cloud cover, and the bulk of functional habitats below one optical depth.

An even more serious problem is that, despite its economic and ecological importance to the nation, about 40% of the Florida Keys remains unmapped. The majority of Florida Bay, most of the area from Key West past the Dry Tortugas, and "unmapped areas" depicted on the CD-ROM maps remain to be characterized. Some of the Keys' most productive coral reefs fall in these areas. Places like the Marquesas and the Dry Tortugas, where NOAA's National Marine Sanctuary Program and the U.S. National Park Service are currently in the process of establishing innovative spatial protection zones to conserve marine biodiversity and build sustainable fisheries. As a result, these areas and, in particular, the Dry Tortugas region, are high-priority areas for additional mapping. In fact, both the Florida Governor's Office and NOAA's advisory council to the Florida Keys National Marine Sanctuary and the National Park Service have identified the Dry Tortugas as a "High Priority" area for mapping.

Pacific Ocean

While approximately 85% of U.S. coral ecosystems are found in the Pacific Ocean (Clark and Gulko 1999), only a small fraction of these reefs have been digitally mapped at a resolution sufficient for management, research and monitoring activities. Fortunately, the Working Group was able to develop a comprehensive strategy to map these coral reefs by drawing on the experience of researchers and managers and the results of applied mapping studies conducted in Florida, the Caribbean and Hawaii.

The first step in developing the Working Group's mapping strategy (MISWG 1999a) for the Pacific Islands was to conduct a comprehensive inventory of existing digital coral reef maps. The Working Group conducted an intensive reconnaissance effort throughout several major Pacific islands. The work was conducted through four site visits (to Hawaii, Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa), a mailed questionnaire, and via phone and electronic mail. This effort identified much data to support coral reef mapping (e.g., existing aerial photography) as well as priority areas for mapping at relatively high resolution. Priorities were defined based on ecological, political and economic concerns (Table 2). Each of the major island areas, and a summary of the Working Group's findings, are briefly described below. Tables 2 and 3 summarize the islands' and state partners' needs, and the costs associated with developing digital benthic habitat maps at both high and low resolutions. The working group recognizes that producing coral reef ecosystem maps for accessible areas will be significantly easier than for remote areas. The cost of in-situ groundtruthing, acquiring georeferenced mapping data, and other logistical-support activities will be far greater in these areas.

(3) Hawaii

For the state of Hawaii, the highest-priority is benthic habitat mapping of the eight main Hawaiian Islands and the surrounding small islands and reefs. The northwest Hawaiian Islands have been identified as a priority by NOAA's National Marine Fisheries Service and the U.S. Fish and Wildlife Service. It was agreed, however, that data acquisition must first be conducted for the eight main islands. The geographic area priorities are: the southern coasts of the main Hawaiian Islands (except Lanai and Niihau), all of Oahu, and eastern coast of Maui. The Working Group's recommendation is to conduct experimental high-resolution mapping in the northwest Hawaiian Islands, including Midway, in combination with satellite-based remote sensing, during the first few years of study. Midway Atoll, at the extreme northwest end of the Northwestern Hawaiian island chain, is under U.S. jurisdiction, but is not a part of the State of Hawaii. As it is generated, digital data will be rapidly transferred to the Hawaiian partners, These data include georeferenced TIFF images of both aerial photos and hyperspectral imagery. In addition, where appropriate, raw imagery of full hyperspectral bands for selected areas should be made available to meet multiple assessment needs.

In Hawaii, some citizens and institutions raised the concern that providing high-resolution maps to the public could increase the potential for exploitation of coral resources. The Working Group offered several ideas for minimizing this concern, including investigating the possibility of degrading the geopositional accuracy of selected map features. Also, as draft coral reef ecosystem maps are reviewed and verified, generalization of certain features may be considered in response to concerns about the depiction of cultural sites.

(4) Territories, Commonwealth and Freely Associated States

The islands of Guam, American Samoa and the Commonwealth of the Northern Mariana Islands (CNMI) were determined, by consensus, to be high-priority areas for mapping at the highest level or resolution practicable. These small but important islands could use maps immediately to protect, conserve and manage their coral reef ecosystems. While only some of these islands may need the high-resolution maps derived from data collected by aircraft, all the islands should be comprehensively mapped using data from satellites, such as Landsat 7. In addition, every attempt should be made to acquire high resolution imagery of Howland Island and Baker Island. Both are small islands near the air transit corridor between Hawaii and American Samoa. These islands possess areas of high biodiversity. However, due to their remoteness, any mission to acquire imagery of these islands will require special logistical support.

(5) Guam

Many institutions, including the Guam Coastal Management Program, Division of Aquatic Wildlife Resources, Guam Environmental Protection Agency, and the University of Guam, require high-resolution maps of coral reefs to support their coastal zone management and research activities. These activities include boundary delineation of protected areas and the identification of areas having high sediment runoff relative to the location and distribution of coral reefs. The Working Group recommends the use of aircraft platforms to map these benthic habitats at high resolution.

(6) American Samoa

High resolution images are needed to address the issues and challenges faced by American Samoa. Some needs of local agencies include: spatial characterization of reefs and associated benthic habitats, better understanding of the relationship between land and sea, watershed delineation, and mapping products suitable as educational and interpretive tools. Conducting a data acquisition mission to American Samoa requires special logistical planning.

Opportunities may exist to partner with organizations located locally to acquire data. The working group will pursue these opportunities. American Samoa ranks coral reef mapping as a high priority. However, they have indicated to the working group that its final ranking of geographic area priorities will need to await the results of decisions on what Coral Reef Initiative proposals receive funding.

(7) Commonwealth of the Northern Mariana Islands (CNMI)

In the CNMI, the islands of Saipan, Rota and Tinian were identified by the island's Coastal Zone Management Program as the highest-priority islands for high-resolution coral reef mapping. The Working Group's recommendation is to initially map the remaining 11 islands in the archipelago using satellite platforms. If adequate funding becomes available, however, all coral reefs within the CNMI should be mapped using high-resolution technology.

(8) Freely Associated Islands

The Freely Associated Islands have close ties to the United States, which governed these islands for over 40 years as Territories following World War II. The "Freely Associated" Islands (FAI) of Micronesia (i.e., the Republic of the Marshall Islands, the Federated States of Micronesia and the Republic of Palau) possess coral reefs with the highest biodiversity of any US or FAI reef ecosystems. The belief is that the total area of reefs in the FAI is much higher than that of the US Flag Islands. Many of these reefs are believed to be in good to excellent condition. As such, they provide an important "baseline" for studying the effect of both anthropogenic and natural disturbances. They also serve as a source of natural products of potential biomedical value. Reefs within the jurisdiction of the island nations may be among the best choices for marine protected areas of global importance. There are less political and social constraints at establishing MPAs in uninhabited areas, and many are situated near corresponding candidate MPAs in the US Pacific Islands. A mapping mission at Wake Atoll, for example, could be extended to cover several atolls in the Marshall Islands. A mapping mission to Guam could be extended to cover islands and atolls in Palau and the FSM. In concert with other CRTF initiatives to promote establishment of MPAs in the FAI, coral reef mapping in the latter can greatly stimulate, publicize or otherwise assist in these ventures. The renegotiation of the Compacts of Free Association in the next few years could also include economic incentives for the individual FAI committees to establish MPAs and their long-range management. Mapping of these candidate areas would be a crucial first step in this process.

For the Federated States of Micronesia (approximately 607 islands), the Republic of Palau (more than 200 islands) and the Republic of the Marshall Islands (five islands and 29 atolls), the Working Group's recommendation is to use satellite technology for initial coral reef mapping efforts. Due to the vast expanse of these areas, preliminary mapping at relatively low resolution (0.3 to 1 km^2) will allow researchers to identify those areas that require high resolution mapping. In addition, the working group is in discussions with the civilian and classified satellite remote sensing community to determine the best way forward to map these important areas.

(9) Other U.S. Flag Islands

Eight other small islands and atolls in the Pacific are under the jurisdiction of the U.S. government: Midway, Wake, Johnston, and Palmyra Atolls, Kingman Reef, and Jarvis, Howland, and Baker Islands. Of these, all but Wake Atoll, Palmyra Atoll, and Kingman Reef are National Wildlife Refuges and are under administration of the U.S. Fish and Wildlife Service. All eight possess exceptionally important biodiversity values and coral reefs. The working group recommends collection of high resolution imagery of Midway Atoll as part of the northwest Hawaiian Islands mission. The aircraft can also collect imagery along selected corridors in this vast coral reef ecosystem during transit between Midway and the main Islands.

Product Development

A suite of coral reef mapping products was defined by the various potential users of digital benthic habitat maps. Some groups, such as nongovernmental organizations, need worldwide and regionwide coral distribution maps to validate and update existing broad-scale coral distribution databases, for example, the ReefBase database housed at the ICLARM (ReefBase 1998). Digital imagery produced from satellites, such as SeaWifs and Landsat, may provide sufficient data content and resolution for these types of users (Figure 1 provides an example of low- to moderate-resolution imagery). In addition, this type of digital product is sufficient as an interim product for particular areas (e.g., the northwest Hawaiian Islands). In areas in which relatively high populations occur or are increasing, high-resolution digital imagery and hard-copy map products, such as those produced for the Florida Keys (Figures 2 and 3 provide examples of high-resolution imagery and the resultant map product) are required for local management decisions. Many island-based Coastal Zone Management Programs need to conduct spatial analyses to determine sensitive areas requiring increased protection and regulation. As a result, digital coral reef maps must be of sufficient spatial resolution (e.g., 5 m or less) to define the management boundaries of protected areas. Thus, the MIP cost estimates account for both high- and low-resolution products.

Mapping Cost Scenarios and Timing

Mapping coral reef ecosystems is an expensive activity, especially at high resolution. Acquiring imagery and other information requires airplanes, fuel, pilots and crew, landing and takeoff facilities, cameras, film, remote sensing instruments, and good weather. Extensive effort must be expended to establish the ground control locations needed for georeferencing the digital data. Once the information is acquired, it must be processed into draft maps, checked for accuracy and ground control, reviewed, edited, and finalized. The final coral reef ecosystem maps then need to be made available to the user community as digital data products over the internet and/or other media (e.g., CD-ROMs).

Based on the published literature (Green et al. 1999; Low et al. 1999; NOAA/FMRI 1998) and federal and state agency and private sector experiences in mapping coral and other benthic habitats, cost estimates were derived for data collection, draft digital map development (e.g., classification, field validation), and final digital map product costs. An estimated $500/sq km is required to produce high resolution digital coral reef maps. This value was used to estimate high resolution mapping costs based on Hunter et al. (1995) estimates of coral reef area by island (Table 2). For the six major Island and State areas that require high resolution coral reef maps, cost was estimated to be approximately $9,150,000. For all US coral reefs found in State, Territories, and Freely Associated States, low resolution (30 sq. m pixels) digital coral reef maps were estimated to cost approximately $450,000 (Table 3). Thus, the estimated total costs for digital mapping of US coral reef ecosystems is approximately $9.2 million dollars.

It must be noted that very little information exists to accurately derive the costs of mapping all U.S. coral reefs. Moreover, the costs of mapping remote areas, such as the northwest Hawaiian islands or the Republic of Palau, will be higher than areas like Puerto Rico or the eight main Hawaiian islands. Based on potential cost estimate errors (plus or minus 25%), changes in cost due to gains in technology and economic inflation, it is estimated that, over the next five–seven years, the cost of developing high resolution coral reef maps could range from $6 to $15 million dollars. If funding is obtained to initiate data collection and map product development, a detailed technical specification document will be developed. That document will have detailed cost estimates for data acquisition, data processing, data validation and logistical support, map verification, and final map product development and distribution.

Table 4 shows three funding scenarios assuming zero funding, $500K, and $1 million dollars per year allocated to digital mapping of benthic habitats for all U.S. coral reef ecosystems. Under a "no new money" scenario, only draft products can be developed for the U.S. Virgin Islands and Puerto Rico. NOAA plans to reprioritize internal funding so that data collection can take place for at least a portion of the main eight Hawaiian Islands during fiscal 2000. No monies are currently available for data processing or map development. Scenario 2 ($500k/yr) will enable digital high resolution map products to be developed for the USVI, Puerto Rico, eight main Hawaiian Islands, Guam, CNMI, and American Samoa by 2005. At this level of funding, high resolution products cannot be developed for the northwest Hawaiian Islands by 2007. At the $1 million per year funding level for seven years, most of the high-priority island areas could receive high-resolution digital coral reef maps. However, even under this funding scenario, the gaps in Florida Keys benthic habitat maps could not be completed. Approximately $1.3 to $1.8 million/year would be required to complete digital maps for all U.S. coral reefs within the proposed 5 to 7 year time-frame.

The order of geographic mapping priorities was based on the consensus reached among island and state partners and MISWG members using several criteria. These criteria included ecosystem stress (population), lack of digital maps, extent of coral coverage, mapping priority in the *All US Islands Coral Reef Plan*, and cost of mapping relative to other coral reef-related activities. The most difficult region to map will be the northwest Hawaiian Islands due to the great extent of coral area and inherent logistical problems. Therefore, the northwest Hawaiian Islands was ranked fourth for high resolution data collection, because of the relatively high costs ($5.8 million) to map this area. High resolution satellites of the near future may significantly decrease the costs of digital coral mapping in expansive areas, such as the northwest Hawaiian Islands.

Table 2. Mapping priorities and estimated costs ($K) for high-resolution digital mapping of benthic habitats

Priority	Location	Reef Area (km^2)	Data Collection	Draft Maps	Final Product	Total Cost
†	Puerto Rico/USVI	5201			200	200
1	Main 8 Hawaiian Islands	2535	350	650	350	1350
2a	Guam	179	50	50	50	150
2b	CNMI	579	100	150	100	350
3	Amer. Samoa	296	50	100	50	200
4	NW Hawaiian Islands	11331	1450	2850	1450	5750
5	Midway	223	50	100	50	200
6	Florida Keys	988	150	250	150	550
7	other*	706	100	200	100	400
					total:	**9150**

† Approximately $200K needed to complete project.

Estimates of Pacific coral reef ecosystem area in Table 2 are from Hunter (1995). Caribbean coral reef ecosystem area estimates are from Miller and Crosby (1998), except for the Florida Keys, where the reef ecosystem area was estimated as that portion not mapped in the *Benthic Habitats of the Florida Keys* project (NOAA/FMRI 1998). The order of mapping priorities is based on: (1) population/ecosystem stress level, (2) lack of existing maps, (3) coral area, (4) priorities identified in the *All Islands Plan,* and (5) cost of mapping relative to other areas. Values (expressed in $1000s) were determined by multiplying the area to be mapped by the estimated cost of mapping per unit area (data collection=$125 per sq km; draft maps=$250 per sq km; final product=$125 per sq km) and then rounding up to the nearest $50,000 to simplify presentation.

* Johnston, Palmyra, and Wake Atolls, Baker, Jarvis, and Howland Islands, Kingman Reef, and Freely Associated States. Cost estimates for these islands do not include the transport of equipment and aircraft between remote locations.

Figure 1. Example of low- to moderate-resolution (satellite) imagery of Long Key area, Florida Keys

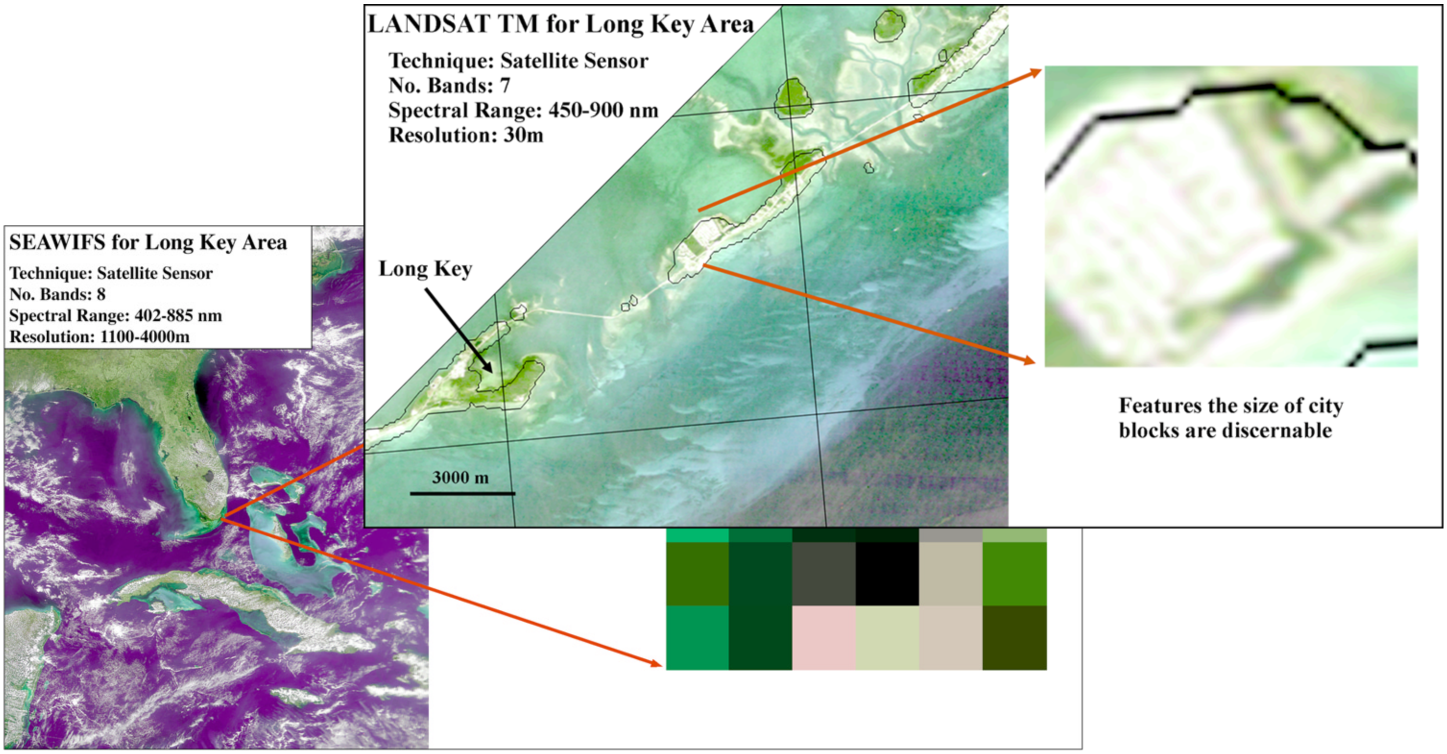


Figure 2. Example of high-resolution (aerial) imagery of Long Key area, Florida Keys

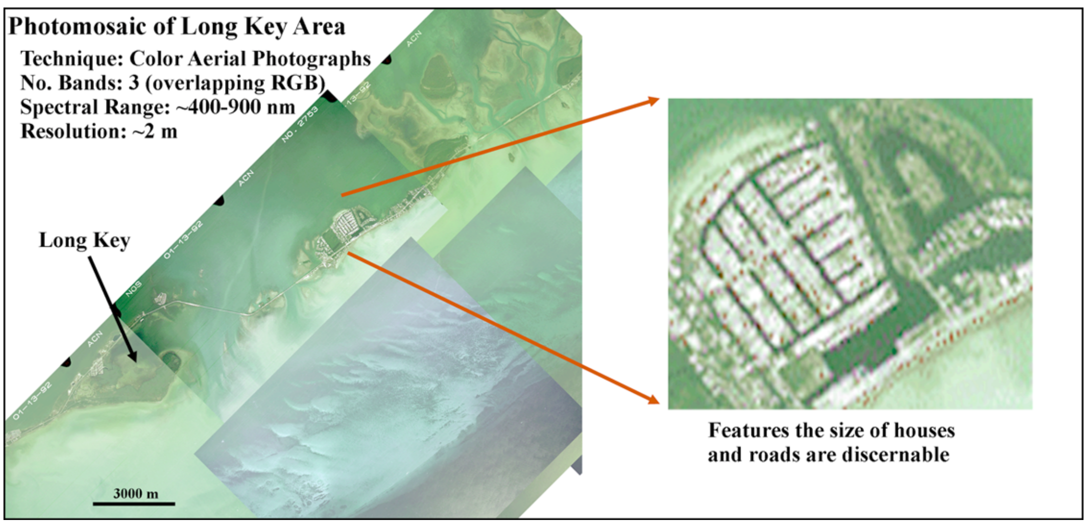


Figure 3. Example of GIS product using aerial photography that was classified into seven benthic habitat types

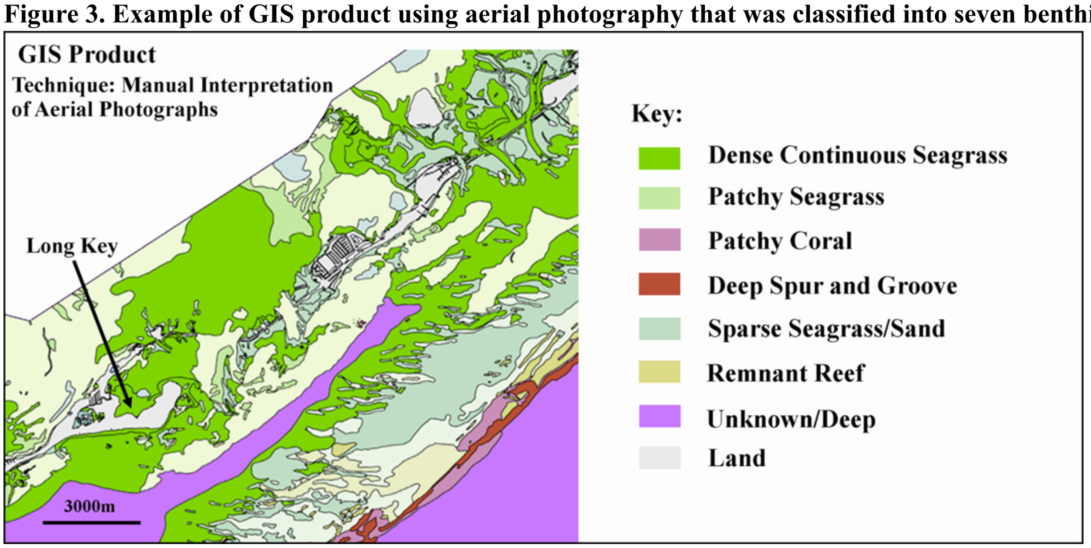


Table 3a-b. Estimated costs ($K) for Landsat TM(a) and SeaWiFS(b) low and moderate resolution digital coral reef mapping

3a. Landsat TM (Thematic Mapper)

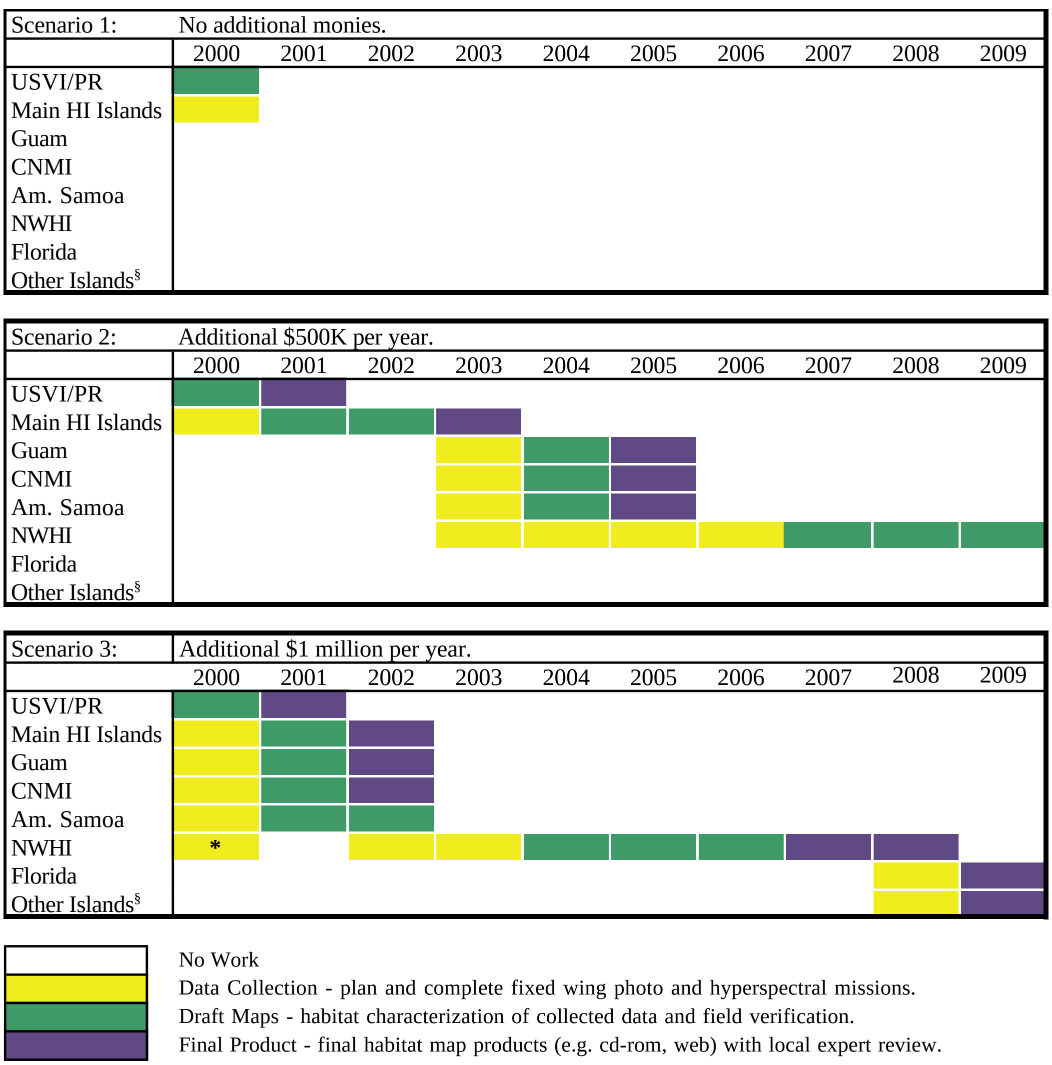
Location	Scenes	Historical Imagery ($3K/scene)	Labor ($2.8K/scene)	Hardware	Other ($0.7K/scene)	Total ($7.5K/scene)	Landsat 7 Imagery ($650/scene)
PR/USVI	3	$9.0K	$8.4K		$2.1K	$22.5K	$2.0K
Main HI Islands	10	$30.0K	$28.0K		$7.0K	$75.0K	$6.5K
Guam/CNMI	8	$24.0K	$22.4K		$5.6K	$60.0K	$5.2K
NW HI Islands	15	$45.0K	$42.0K	$60.0K	$10.5K	$112.5K	$9.8K
Midway	1	$3.0K	$2.8K		$0.7K	$7.5K	$0.7K
Am. Samoa	3	$9.0K	$8.4K		$2.1K	$22.5K	$2.0K
Florida	4	$12.0K	$11.2K		$2.8K	$30.0K	$2.6K
Miscellaneous§	17	$51.0K	$47.6K		$11.9K	$127.5K	$11.1K
						Total Cost	**Total Cost**
Total	61	$183K	$171K	$60K	$43K	**$458K**	**$40K**

§ Jarvis, Johnson, Palmyra and Wake Atolls and Baker, Howland and Kingman reefs, and Freely Associated States.

3b. SeaWiFs (Sea-Viewing Wide Field of View Sensor)

Annual Expense under NASA Management	
Labor	$15K
Travel/Supplies	$3K
Publication	$7K
Total Cost	$25K

Table 4. High resolution coral reef mapping under three funding scenarios



* Pilot study - approximately 20% of total data collection.

§ Jarvis, Johnson, Palmyra and Wake Atolls and Baker, Howland and Kingman reefs, and Freely Associated States.

Capacity Building in Islands and States

Based on discussions held with territory and island partners during the Working Group's reconnaissance trips, map products should be incorporated into the data acquisition and distribution plans to ensure that useful management products can be derived from the raw data. If federal resources are provided to island and state communities, a process needs to be established to ensure these partners receive the most useful mapping products. Most importantly, the U.S. Coral Reef Task Force and its Mapping and Information Synthesis Working Group must take an active role in ensuring the user community actively participates in the development, generation, distribution, and use of the coral reef ecosystem maps. This "capacity-building" will bridge the gap between one-time synoptic mapping efforts and coral reef ecosystem management. It also will elevate mapping efforts from "snapshot" investigations to the continual spatial monitoring of coral reef habitats. For example, an initial activity is under way in the U.S. Virgin Islands and Puerto Rico to develop a Classification Manual that describes methods and protocols for habitat classification and the development of map products. These types of products will aid in capacity-building throughout all of the islands associated with the United States.

VI. NEXT STEPS

This draft of the MIP will be submitted to the U.S. Coral Reef Task Force at the November task force meeting. Comments received from the task force and the public will be integrated into the next version of the MIP. This document will continue to evolve based upon mapping priorities and availability of funds. Please submit comments and questions to:

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IX. APPENDICES

Appendix 1. Working Group Members and Partners

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Julie Robinson, NASA
George Rohaley, USDA, NRCS
Steven O. Rohmann, NOAA
Captain Robert G. Ross, U.S. Coast Guard
Don Scavia, NOAA
Lois Schiffer, U.S. Department of Justice
Robert Schroeder, Western Pacific Regional Fisheries Management Council
Richard Seman, CNMI Government
Robert P. Smith, U.S. Fish and Wildlife Service
Jack Sobel, Center For Marine Conservation
Michael Soukup, NPS
Susan Saucerman, EPA
Paul Souza, FWS
CDR Barry Stamey, U.S. Navy
Alan Strong, NOAA
Andy Tafileichig, Yap, FSM
Franklyn Tan Te, College of the Marshall Islands
Phillip Taylor, USNSF
Jim Tilmant, NPS
Brian Tissot, University of Washington
Paul Thomas, Virgin Islands CZM
Allen Tom, Humpback Whale National Marine Sanctuary
Douglas Tom, Hawaii Dept. of Business, Economic Development and Tourism
Kirk Waters, NOAA
Steve Wegener, NASA
S. Jeffress (Jeff) Williams, USGS - *MISWG Co-Chair*
L. Dorsey Worthy, NOAA
C. Wayne Wright, NASA
Sally J. Yozell, NOAA

Appendix 2. List of available data and information to support coral reef mapping by island, state, commonwealth and territory

Information Source	Date* Developed	Information Description
American Samoa		
USGS	1990	Digital Orthophoto Quads
NOAA/HAZMAT	1999	Environmental Sensitivity Index maps being updated
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for five islands
NPS	n/a	digital data set of beach and nearshore reef communities for a 2 mile portion of Ofu Island
FWS	n/a	National Wetlands Inventory maps indicating presence/absence of coral
NOAA/NGDC	n/a	deep water NOAA/NOS bathymetric sounding data
Commonwealth of the Northern Mariana Islands		
USGS	1990	Digital Orthophoto Quads
U.S. Navy	ongoing	will conduct bathymetric surveys and B&W aerial photo mission to Tinian and Farallon de Mendilla
CRM	1999	numerous terrestrial and aquatic thematic data layers (e.g., coral presence/absence) digitized from USGS topographic sheets for Saipan
NOAA/HAZMAT	1999	Environmental Sensitivity Index map for Saipan available
CRM	1999	1:10K color aerial photography acquired
CRM	1996	1:10K color aerial photography available
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for eight islands
FWS	n/a	National Wetlands Inventory maps for Saipan
Federated States of Micronesia		
Univ. of Guam	1998	shoreline and coral reef extent for Kosrae, Chuuk, Pohnpei, and Yap digitized from 1:24K USGS topographic sheets
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for Kosrae, Chuuk, Pohnpei, and Yap (plus some other islands)
Guam		
USGS	1990	Digital Orthophoto Quads
NOAA/HAZMAT	1999	Environmental Sensitivity Index map for Saipan available
Univ. of Guam	1998	shoreline and coral reef extent thematic data layers digitized from1:24K USGS topographic sheets
GovGuam	1995	1:20K color aerial photographs of most of Guam available.
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography
NPS	ongoing	To be scanned, georeferenced and mosaiced during FY2000 for base map to preliminary reef inventory assessment by University of Guam/NPS. Natural color stereo aerial photography with associated ground control information: Agat Beach/Reef - 3 flight lines,
FWS	n/a	National Wetlands Inventory maps available
Hawaiian Islands (Main Eight)		
NRCS	ongoing	acquisition of 1:6K digital imagery to delineate 11 and 14-digit hydrologic units and to use in watershed assessment projects.
USGS	1990	Digital Orthophoto Quads
WPFMC	1999	generalized (various scales) GIS maps of islands and political boundaries (e.g., EEZ) used for FMP.
Univ. of Hawaii	1999	800+ in-situ spectra of coral reef ecosystem localities
DLNR	1994	SPOT images of eight main islands.
NOAA/NOS	1994	1:35K scale color aerial photographs of eight main islands
NOAA/HAZMAT	1985	Environmental Sensitivity Index maps available
DLNR	n/a	numerous digital data files available, including shoreline, some reef extent polygons, and some general bathy
NOAA	n/a	5 arcsecond bathy for entire Pacific region
Oahu		
Univ. of Hawaii	1998	Digital Airborne MSS data and georeferenced map (1:10,000) of reef and nearshore on Windward Oahu, Kailua - water depths 0 to 40m(original pixel resolution - 1m). Data are being trained/modeled with bathymetric data, and substrate classification currently

Information Source	Date* Developed	Information Description
Maui		
Univ. of Hawaii	1998	digital bathymetry and coral cover in and around Maalaea harbor.
COE	1998	low altitude bathymetric LIDAR for all of island
Molokai		
USGS	1999	1:10,000 scale color aerial photos of south shore of island
COE	1999	low altitude bathymetric LIDAR for south shore of island
Ogden Environ.	1994	reef coverages for portions of southeast Molokai
Kauai		
COE	1999	low altitude bathymetric LIDAR for south shore of island
Ogden Environ.	1994	reef coverages for portions of north Kauai
Hawaii		
Ogden Environ.	1994	reef coverages for Puako area in North Kohala district of the island
Lanai		
Ogden Environ.	1994	reef coverages for eastern portion of island
Northwest Hawaiian Islands		
FWS	n/a	digital maps of numerous themes, including NWHI wildlife refuges
Puerto Rico		
NOAA/NOS	ongoing	project underway to digitally map coral reef ecosystems from 1:20K and 1:48K color aerial photography and hyperspectral instruments
NOAA/NOS	1999	aerial photography at 1:24K and 1:48K scales
USGS/BRD	1999	benthic habitat maps of Vieques island and and Roosevelt Roads NAS at 1:9,600 scale
NOAA/NGDC	n/a	NOAA/NOS bathymetric sounding data at 3 arc second intervals
USGS	n/a	digital and hard copy maps of sediments, reefs, and detailed bathymetry for segments of the coastline
FWS	n/a	National Wetlands Inventory maps indicating presence/absence of coral
Republic of Palau		
Univ. of Guam	1998	shoreline and coral reef extent for Babeldaob digitized from 1:24K USGS topographic sheets
NOAA/NOS	1994	partial (some clouds) 1:35K scale color aerial photography for Babeldaob, Oreor, Belilou, and Ngeaur
U.S. Virgin Islands		
NOAA/NOS	ongoing	project underway to digitally map coral reef ecosystems from 1:20K and 1:48K color aerial photography and hyperspectral instruments
NOAA/NOS	1999	color aerial photography at 1:24K and 1:48K scales
NOAA/HAZMAT	1999	Environmental Sensitivity Index maps recently reviewed and updated
CDC/TNC	1999	Rapid Ecological Assessment maps for St.John and St.Thomas
CDC/TNC	1998	Rapid Ecological Assessment Maps for St.Croix
NPS of USVI	1986	marine habitat maps for St.John at 1:5,300 scale
NOAA/NGDC	n/a	NOAA/NOS bathymetric sounding data at 3 arc second intervals

* Date of product development does not necessarily mean date of data collection.